FORMULA AND CHART TABLE FOR CIMT 210

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CODE

COMMENTARY

3.3 — Aggregates

3.3.1 — Concrete aggregates shall conform to one of the following specifications:

(a) "Specification for Concrete Aggregates" (ASTM C 33).

(b) "Specification for Lightweight Aggregates for Structural Concrete" (ASTM C 330).

Exception: Aggregates which have been shown by special test or actual service to produce concrete of adequate strength and durability and approved by the building official.

3.3.2 — Nominal maximum size of coarse aggregate shall be not larger than:

(a) $^1/_5$ the narrowest dimension between sides of forms, nor

(b) $^1/_3$ the depth of slabs, nor

(c) $^3/_4$ the minimum clear spacing between individual reinforcing bars or wires, bundles of bars, or prestressing tendons or ducts.

These limitations shall not apply if, in the judgment of the engineer, workability and methods of consolidation are such that concrete can be placed without honeycomb or voids.

3.4 — Water

3.4.1 — Water used in mixing concrete shall be clean and free from injurious amounts of oils, acids, alkalis, salts, organic materials, or other substances deleterious to concrete or reinforcement.

R3.3 — Aggregates

R3.3.1 — It is recognized that aggregates conforming to the ASTM specifications are not always economically available and that, in some instances, noncomplying materials have a long history of satisfactory performance. Such nonconforming materials are permitted with special approval when acceptable evidence of satisfactory performance is provided. It should be noted, however, that satisfactory performance in the past does not guarantee good performance under other conditions and in other localities. Whenever possible, aggregates conforming to the designated specifications should be used.

R3.3.2 — The size limitations on aggregates are provided to ensure proper encasement of reinforcement and to minimize honeycomb. Note that the limitations on maximum size of the aggregate may be waived if, in the judgment of the engineer, the workability and methods of consolidation of the concrete are such that the concrete can be placed without honeycomb or voids. In this instance, the engineer must decide whether or not the limitations on maximum size of aggregate may be waived.

R3.4 — Water

R3.4.1 — Almost any natural water that is drinkable (potable) and has no pronounced taste or odor is satisfactory as mixing water for making concrete. Impurities in mixing water, when excessive, may affect not only setting time, concrete strength, and volume stability (length change), but may also cause efflorescence or corrosion of reinforcement. Where possible, water with high concentrations of dissolved solids should be avoided.

Salts, or other deleterious substances contributed from the aggregate or admixtures are additive to the amount which might be contained in the mixing water. These additional amounts must be considered in evaluating the acceptability of the total impurities that may be deleterious to concrete or steel.

aggregate to obtain a desired grading, provided that the gradings are not otherwise restricted by the project specifier and the nominal maximum size indicated by the size number is not exceeded,

4.3.3.2 The class designation (see 11.1 and Table 3),

4.3.3.3 Whether the restriction on reactive materials in 11.2 applies,

4.3.3.4 In the case of the sulfate soundness test (see Table 3), which salt is to be used. If none is stated, either sodium sulfate or magnesium sulfate shall be used, and

4.3.4 The person responsible for selecting the concrete proportions if other than the concrete producer.

4.3.5 Any exceptions or additions to this specification (see Note 1).

FINE AGGREGATE

5. General Characteristics

5.1 Fine aggregate shall consist of natural sand, manufactured sand, or a combination thereof.

6. Grading

6.1 *Sieve Analysis*—Fine aggregate, except as provided in 6.2 and 6.3 shall be graded within the following limits:

Sieve (Specification E 11)	Percent Passing
9.5-mm (3/8-in.)	100
4.75-mm (No. 4)	95 to 100
2.36-mm (No. 8)	80 to 100
1.18-mm (No. 16)	50 to 85
600-µm (No. 30)	25 to 60
300-µm (No. 50)	5 to 30
150-µm (No. 100)	0 to 10

NOTE 2—Concrete with fine aggregate gradings near the minimums for percent passing the 300 µm (No.50) and 150 µm (No.100) sometimes have difficulties with workability, pumping or excessive bleeding. The addition of entrained air, additional cement, or the addition of an approved mineral admixture to supply the deficient fines, are methods used to alleviate such difficulties.

6.2 The fine aggregate shall have not more than 45 % passing any sieve and retained on the next consecutive sieve of those shown in 6.1, and its fineness modulus shall be not less than 2.3 nor more than 3.1.

6.3 Fine aggregate failing to meet these grading requirements shall meet the requirements of this section provided that the supplier can demonstrate to the purchaser or specifier that concrete of the class specified, made with fine aggregate under consideration, will have relevant properties (see Note 4) at least equal to those of concrete made with the same ingredients, with the exception that the reference fine aggregate shall be selected from a source having an acceptable performance record in similar concrete construction.

NOTE 3—Fine aggregate that conforms to the grading requirements of a specification, prepared by another organization such as a state transportation agency, which is in general use in the area, should be considered as having a satisfactory service record with regard to those concrete properties affected by grading.

NOTE 4—Relevant properties are those properties of the concrete that are important to the particular application being considered. STP 169C[8] provides a discussion of important concrete properties.

6.4 For continuing shipments of fine aggregate from a given source, the fineness modulus shall not vary more than 0.20 from the base fineness modulus. The base fineness modulus shall be that value that is typical of the source. The purchaser or specifier has the authority to approve a change in the base fineness modulus.

NOTE 5—The base fineness modulus should be determined from previous tests, or if no previous tests exist, from the average of the fineness modulus values for the first ten samples (or all preceding samples if less than ten) on the order. The proportioning of a concrete mixture may be dependent on the base fineness modulus of the fine aggregate to be used. Therefore, when it appears that the base fineness modulus is considerably different from the value used in the concrete mixture, a suitable adjustment in the mixture may be necessary.

7. Deleterious Substances

7.1 The amount of deleterious substances in fine aggregate shall not exceed the limits prescribed in Table 1.

7.2 *Organic Impurities*:

7.2.1 Fine aggregate shall be free of injurious amounts of organic impurities. Except as herein provided, aggregates subjected to the test for organic impurities and producing a color darker than the standard shall be rejected.

7.2.2 Use of a fine aggregate failing in the test is not prohibited, provided that the discoloration is due principally to the presence of small quantities of coal, lignite, or similar discrete particles.

7.2.3 Use of a fine aggregate failing in the test is not prohibited, provided that, when tested for the effect of organic impurities on strength of mortar, the relative strength at 7 days, calculated in accordance with Test Method C 87, is not less than 95 %.

7.3 Fine aggregate for use in concrete that will be subject to wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials that are deleteriously reactive with the alkalies in the cement in an amount sufficient to cause excessive expansion of mortar or concrete, except that if such materials are present in injurious amounts, use of the fine aggregate is not prohibited when used with a cement containing less than 0.60 % alkalies calculated as sodium oxide equivalent (Na_2O + $0.658K_2O$) or with the addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction. (See Appendix X1.)

8. Soundness

8.1 Except as provided in 8.2 and 8.3, fine aggregate subjected to five cycles of the soundness test shall have a weighted average loss not greater than 10 % when sodium sulfate is used or 15 % when magnesium sulfate is used.

8.2 Fine aggregate failing to meet the requirements of 8.1 shall be regarded as meeting the requirements of this section provided that the supplier demonstrates to the purchaser or

[8] *Significance of Tests and Properties of Concrete and Concrete Making Materials*, STP 169C, ASTM, 1994.

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TABLE 2 Grading Requirements for Coarse Aggregates

Size Number	Nominal Size (Sieves with Square Openings)	Amounts Finer than Each Laboratory Sieve (Square-Openings), Weight Percent												
		4 in. (100 mm)	3½ in. (90 mm)	3 in. (75 mm)	2½ in. (63 mm)	2 in. (50 mm)	1½ in. (37.5 mm)	1 in. (25.0 mm)	¾ in. (19.0 mm)	½ in. (12.5 mm)	⅜ in. (9.5 mm)	No. 4 (4.75 mm)	No. 8 (2.36 mm)	No. 16 (1.18 mm)
1	3½ to 1½ in. (90 to 37.5 mm)	100	90 to 100	...	25 to 60	...	0 to 15	...	0 to 5	...	...	...	...	...
2	2½ to 1½ in. (63 to 37.5 mm)	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...
3	2 to 1 in. (50 to 25.0 mm)	...	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...
357	2 in. to No. 4 (50 to 4.75 mm)	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	...	0 to 5	...	...
4	1½ to ¾ in. (37.5 to 19.0 mm)	...	...	...	...	100	90 to 100	20 to 55	0 to 15	...	0 to 5	...	...	...
467	1½ in. to No. 4 (37.5 to 4.75 mm)	...	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	0 to 5	...	...
5	1 to ½ in. (25.0 to 12.5 mm)	...	...	...	...	...	100	90 to 100	20 to 55	0 to 10	0 to 5	...	...	...
56	1 to ⅜ in. (25.0 to 9.5 mm)	...	...	...	...	...	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	...	...
57	1 in. to No. 4 (25.0 to 4.75 mm)	...	...	...	...	...	100	95 to 100	...	25 to 60	...	0 to 10	0 to 5	...
6	¾ to ⅜ in. (19.0 to 9.5 mm)	...	...	...	...	...	...	100	90 to 100	20 to 55	0 to 15	0 to 5	...	...
67	¾ in. to No. 4 (19.0 to 4.75 mm)	...	...	...	...	...	...	100	90 to 100	...	20 to 55	0 to 10	0 to 5	...
7	½ in. to No. 4 (12.5 to 4.75 mm)	...	...	...	...	...	...	...	100	90 to 100	40 to 70	0 to 15	0 to 5	...
8	⅜ in. to No. 8 (9.5 to 2.36 mm)	...	...	...	...	...	...	...	...	100	85 to 100	10 to 30	0 to 10	0 to 5

6.3 The fine aggregate shall have not more than 45 % passing any sieve and retained on the next consecutive sieve

NOTE 5—The base fineness modulus should be determined from previous tests, or if no previous tests exist, from the average of the cold weather, and the presence of chemical admixtures not formulated especially for acceleration.

Because of the possible adverse effects on finishing time and consequent labor costs, in some cold climates the proportion of other cementitious materials in the blend may have to be reduced below the optimum amount for strength considerations. Some Class C fly ashes may affect setting time while some other cementitious materials may have little effect on setting time. Any reduction in cement content will reduce heat generation and normally prolong the setting time.

CHAPTER 5 – BACKGROUND DATA

5.1 To the extent possible, selection of concrete proportions should be based on test data or experience with the materials actually to be used. Where such background is limited or not available, estimates given in this recommended practice may be employed.

5.2 The following information for available materials will be useful:

5.2.1 Sieve analyses of fine and coarse aggregates.

5.2.2 Unit weight of coarse aggregate.

5.2.3 Bulk specific gravities and absorptions of aggregates.

5.2.4 Mixing-water requirements of concrete developed from experience with available aggregates.

5.2.5 Relationships between strength and water-cement ratio or ratio of water-to-cement plus other cementitious materials, for available combinations of cements, other cementitious materials if considered, and aggregates.

5.2.6 Specific gravities of portland cement and other cementitious materials, if used.

5.2.7 Optimum combination of coarse aggregates to meet the maximum density gradings for mass concrete as discussed in Section 5.3.2.1 of Appendix 5.

5.3 Estimates from Tables 6.3.3 and 6.3.4, respectively, may be used when items in Section 5.2.4 and Section 6.3.5 are not available. As will be shown, proportions can be estimated without the knowledge of aggregate-specific gravity and absorption, Section 5.2.3.

CHAPTER 6 – PROCEDURE

6.1 The procedure for selection of mix proportions given in this section is applicable to normal weight concrete. Although the same basic data and procedures can be used in proportioning heavyweight and mass concretes, additional information and sample computations for these types of concrete are given in Appendixes 4 and 5, respectively.

6.2 Estimating the required batch weights for the concrete involves a sequence of logical, straightforward steps which, in effect, fit the characteristics of the available materials into a mixture suitable for the work. The question of suitability is frequently not left to the individual selecting the proportions. The job specifications may dictate some or all of the following:

6.2.1 Maximum water-cement or water-cementitious material ratio.

6.2.2 Minimum cement content.

6.2.3 Air content.

6.2.4 Slump.

6.2.5 Maximum size of aggregate.

6.2.6 Strength.

6.2.7 Other requirements relating to such things as strength overdesign, admixtures, and special types of cement, other cementitious materials, or aggregate.

6.3 Regardless of whether the concrete characteristics are prescribed by the specifications or are left to the individual selecting the proportions, establishment of batch weights per yd^3 of concrete can be best accomplished in the following sequence:

6.3.1 *Step 1. Choice of slump* – If slump is not specified, a value appropriate for the work can be selected from Table 6.3.1. The slump ranges shown apply when vibration is used to consolidate the concrete. Mixes of the stiffest consistency that can be placed efficiently should be used.

Table 6.3.1 — Recommended slumps for various types of construction*

Types of construction	Slump, in.	
	Maximum[†]	Minimum
Reinforced foundation walls and footings	3	1
Plain footings, caissons, and substructure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

*Slump may be increased when chemical admixtures are used, provided that the admixture-treated concrete has the same or lower water-cement or water-cementitious material ratio and does not exhibit segregation potential or excessive bleeding.

†May be increased 1 in. for methods of consolidation other than vibration.

6.3.2 *Step 2. Choice of maximum size of aggregate* – Large nominal maximum sizes of well graded aggregates have less voids than smaller sizes. Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete. Generally, the nominal maximum size of aggregate should be the largest that is economically available and consistent with dimensions of the structure. In no event should the nominal maximum size exceed one-fifth of the narrowest dimension between sides of forms, one-third the depth of slabs, nor three-fourths of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pretensioning strands. These limitations are sometimes waived if workability and methods of consolidation are such that the concrete can be placed without honeycomb or void. In areas congested with reinforcing steel, post-tension ducts or conduits, the proportioner should select a nominal maximum size of the aggregate so concrete can be placed without excessive segregation, pockets, or voids. When high strength concrete is desired, best results may be obtained with reduced nominal maximum sizes of aggregate since these produce higher strengths at a given water-cement ratio.

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Table 6.3.3 — Approximate mixing water and air content requirements for different slumps and nominal maximum sizes of aggregates

	Water, lb/yd³ of concrete for indicated nominal maximum sizes of aggregate							
Slump, in.	⅜ in.*	½ in.*	¾ in.*	1 in.*	1-½ in.*	2 in.*†	3 in.†‡	6 in.†‡
	Non-air-entrained concrete							
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	—
More than 7*	—	—	—	—	—	—	—	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
1 to 2	305	295	280	270	250	240	205	180
3 to 4	340	325	305	295	275	265	225	200
6 to 7	365	345	325	310	290	280	260	—
More than 7*	—	—	—	—	—	—	—	—
Recommended averages§ total air content, percent for level of exposure:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5**††	1.0**††
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5**††	3.0**††
Severe exposure‡‡	7.5	7.0	6.0	6.0	5.5	5.0	4.5**††	4.0**††

*The quantities of mixing water given for air-entrained concrete are based on typical total air content requirements as shown for "moderate exposure" in the table above. These quantities of mixing water are for use in computing cement contents for trial batches at 68 to 77 F. They are maximum for reasonably well-shaped angular aggregates graded within limits of accepted specifications. Rounded aggregate will generally require 30 lb less water for non-air-entrained and 25 lb less for air-entrained concretes. The use of water-reducing chemical admixtures, ASTM C 494, may also reduce mixing water by 5 percent or more. The volume of the liquid admixtures is included as part of the total volume of the mixing water. The slump values of more than 7 in. are only obtained through the use of water-reducing chemical admixture; they are for concrete containing nominal maximum size aggregate not larger than 1 in.

†The slump values for concrete containing aggregate larger than 1½ in. are based on slump tests made after removal of particles larger than 1½ in. by wet-screening.

‡These quantities of mixing water are for use in computing cement factors for trail batches when 3 in. or 6 in. nominal maximum size aggregate is used. They are average for reasonably well-shaped coarse aggregates, well-graded from coarse to fine.

§Additional recommendations for air-content and necessary tolerances on air content for control in the field are given in a number of ACI documents, including ACI 201, 345, 318, 301, and 302. ASTM C 94 for ready-mixed concrete also gives air-content limits. The requirements in other documents may not always agree exactly, so in proportioning concrete consideration must be given to selecting an air content that will meet the needs of the job and also meet the applicable specifications.

**For concrete containing large aggregates that will be wet-screened over the 1½ in. sieve prior to testing for air content, the percentage of air expected in the 1½ in. minus material should be as tabulated in the 1½ in. column. However, initial proportioning calculations should include the air content as a percent of the whole.

††When using large aggregate in low cement factor concrete, air entrainment need not be detrimental to strength. In most cases mixing water requirement is reduced sufficiently to improve the water-cement ratio and to thus compensate for the strength-reducing effect of air-entrained concrete. Generally, therefore, for these large nominal maximum sizes of aggregate, air contents recommended for extreme exposure should be considered even though there may be little or no exposure to moisture and freezing.

‡‡These values are based on the criteria that 9 percent air is needed in the mortar phase of the concrete. If the mortar volume will be substantially different from that determined in this recommended practice, it may be desirable to calculate the needed air content by taking 9 percent of the actual mortar volume.

6.3.3 *Step 3. Estimation of mixing water and air content* -- The quantity of water per unit volume of concrete required to produce a given slump is dependent on: the nominal maximum size, particle shape, and grading of the aggregates; the concrete temperature; the amount of entrained air; and use of chemical admixtures. Slump is not greatly affected by the quantity of cement or cementitious materials within normal use levels (under favorable circumstances the use of some finely divided mineral admixtures may lower water requirements slightly -- see ACI 212.1R). Table 6.3.3 provides estimates of required mixing water for concrete made with various maximum sizes of aggregate, with and without air entrainment. Depending on aggregate texture and shape, mixing water requirements may be somewhat above or below the tabulated values, but they are sufficiently accurate for the first estimate. The differences in water demand are not necessarily reflected in strength since other compensating factors may be involved. A rounded and an angular coarse aggregate, both well and similarly graded and of good quality, can be expected to produce concrete of about the same compressive strength for the same cement factor in spite of differences in w/c or $w/(c + p)$ resulting from the different mixing water requirements. Particle shape is not necessarily an indicator that an aggregate will be either above or below in its strength-producing capacity.

Chemical admixtures -- Chemical admixtures are used to modify the properties of concrete to make it more workable, durable, and/or economical; increase or decrease the time of set; accelerate strength gain; and/or control temperature gain. Chemical admixtures should be used only after an appropriate evaluation has been conducted to show that the desired effects have been accomplished in the particular concrete under the conditions of intended use. Water-reducing and/or set-controlling admixtures conforming to the requirements of ASTM C 494, when used singularly or in combination with other chemical admixtures, will reduce significantly the quantity of water per unit volume of concrete. The use of some chemical admixtures, even at the same slump, will improve such qualities as workability, finishability, pumpability, durability, and compressive and flexural strength. Significant volume of liquid admixtures should be considered as part of the mixing water. The slumps shown in Table 6.3.1, "Recommended Slumps for Various Types of Construction," may be increased when chemical admixtures are used, providing the admixture-treated concrete has the same or a lower water-cement ratio and does not exhibit segregation potential and excessive bleeding. When only used to increase slump, chemical admixtures may not improve any of the properties of the concrete.

Table 6.3.3 indicates the approximate amount of entrapped air to be expected in non-air-entrained concrete in the upper part of the table and shows the recommended average air content for air-entrained concrete in the lower part of the table. If air entrainment is needed or desired, three levels of air content are given for each aggregate size depending on the purpose of the entrained air and the severity of exposure if entrained air is needed for durability.

Mild exposure -- When air entrainment is desired for a beneficial effect other than durability, such as to improve workability or cohesion or in low cement factor concrete to improve strength, air contents lower than those needed for durability can be used. This exposure includes indoor or outdoor service in a climate where concrete will not be exposed to freezing or to deicing agents.

Moderate exposure -- Service in a climate where freezing is expected but where the concrete will not be continually exposed to moisture or free water for long periods prior to freezing and will not be exposed to deicing agents or other aggressive chemicals. Examples include: exterior beams, columns, walls, girders, or slabs that are not in contact with wet soil and are so located that they will not receive direct applications of deicing salts.

Severe exposure -- Concrete that is exposed to deicing chemicals or other aggressive agents or where the concrete may become highly saturated by continued contact with moisture or free water prior to freezing. Examples include: pavements, bridge decks, curbs, gutters, sidewalks, canal linings, or exterior water tanks or sumps.

The use of normal amounts of air entrainment in concrete with a specified strength near or about 5000 psi may not be possible due to the fact that each added percent of air lowers the maximum strength obtainable with a given combination of materials.[1] In these cases the exposure to water, deicing salts, and freezing temperatures should be carefully evaluated. If a member is not continually wet and will not be exposed to deicing salts, lower air-content values such as those given in Table 6.3.3 for moderate exposure are appropriate even though the concrete is exposed to freezing and thawing temperatures. However, for an exposure condition where the member may be saturated prior to freezing, the use of air entrainment should not be sacrificed for strength. In certain applications, it may be found that the content of entrained air is lower than that specified, despite the use of usually satisfactory levels of air-entraining admixture. This happens occasionally, for example, when very high cement contents are involved. In such cases, the achievement of required durability may be demonstrated by satisfactory results of examination of air-void structure in the paste of the hardened concrete.

When trial batches are used to establish strength relationships or verify strength-producing capability of a mixture, the least favorable combination of mixing water and air content should be used. The air content should be the maximum permitted or likely to occur, and the concrete should be gaged to the highest permissible slump. This will avoid developing an over-optimistic estimate of strength on the assumption that average rather than extreme conditions will prevail in the field. If the concrete obtained in the field has a lower slump and/or air content, the proportions of ingredients should be adjusted to maintain required yield. For additional information on air content recommendations, see ACI 201.2R, 301, and 302.1R.

6.3.4 *Step 4. Selection of water-cement or water-cementitious materials ratio* -- The required w/c or $w/(c + p)$ is determined not only by strength requirements but also by factors such as durability. Since different aggregates, cements, and cementitious materials generally produce different strengths at the same w/c or $w/(c + p)$, it is highly desirable to have or to develop the relationship between strength and w/c or $w/(c + p)$ for the materials actually to be used. In the absence of such data, approximate and relatively conservative values for concrete containing Type I portland cement can be taken from Table 6.3.4(a). With typical materials, the tabulated w/c or $w/(c + p)$ should produce the strengths shown, based on 28-day tests of specimens cured under standard laboratory conditions. The average strength selected must, of course, exceed the specific strength by a sufficient margin to keep the number of low tests within specific limits -- see ACI 214 and ACI 318.

Table 6.3.4(a) — Relationship between water-cement or water-cementitious materials ratio and compressive strength of concrete

Compressive strength at 28 days, psi*	Water-cement ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
6000	0.41	—
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

*Values are estimated average strengths for concrete containing not more than 2 percent air for non-air-entrained concrete and 6 percent total air content for air-entrained concrete. For a constant w/c or $w/(c + p)$, the strength of concrete is reduced as the air content is increased. 28-day strength values may be conservative and may change when various cementitious materials are used. The rate at which the 28-day strength is developed may also change.

Strength is based on 6 × 12 in. cylinders moist-cured for 28 days in accordance with the sections on "Initial Curing" and "Curing of Cylinders for Checking the Adequacy of Laboratory Mixture Proportions for Strength or as the Basis for Acceptance or for Quality Control" of ASTM method C 31 for Making and Curing Concrete Specimens in the Field. These are cylinders cured moist at 73.4 ± 3 F (23 ± 1.7 C) prior to testing.

The relationship in this table assumes a nominal maximum aggregate size of about ¾ to 1 in. For a given source of aggregate, strength produced at a given w/c or $w/(c + p)$ will increase as nominal maximum size of aggregate decreases; see Sections 3.4 and 6.3.2.

For severe conditions of exposure, the w/c or $w/(c + p)$ ratio should be kept low even though strength requirements may be met with a higher value. Table 6.3.4(b) gives limiting values.

When natural pozzolans, fly ash, GGBF slag, and silica fume, hereafter referred to as pozzolanic materials, are used in concrete, a water-to-cement plus pozzolanic materials ratio (or water-to-cement plus other cementitious materials ratio) by weight must be considered in place of the traditional water-cement ratio by weight. There are two ap-

Table 6.3.4(b) — Maximum permissible water-cement or water-cementitious materials ratios for concrete in severe exposures*

Type of structure	Structure wet continuously or frequently and exposed to freezing and thawing[†]	Structure exposed to sea water or sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 1 in. cover over steel	0.45	0.40[‡]
All other structures	0.50	0.45[‡]

*Based on report of ACI Committee 201. Cementitious materials other than cement should conform to ASTM C 618 and C 989.

[†]Concrete should also be air-entrained.

[‡]If sulfate resisting cement (Type II or Type V of ASTM C 150) is used, permissible water-cement or water-cementitious materials ratio may be increased by 0.05.

proaches normally used in determining the $w/(c+p)$ ratio that will be considered equivalent to the w/c of a mixture containing only portland cement: (1) equivalent weight of pozzolanic materials or (2) equivalent absolute volume of pozzolanic materials in the mixture. For the first approach, the weight equivalency, the total weight of pozzolanic materials remains the same [that is, $w/(c+p) = w/c$ directly]: but the total absolute volume of cement plus pozzolanic materials will normally be slightly greater. With the second approach, using the Eq. (6.3.4.2), a $w/(c+p)$ by weight is calculated that maintains the same absolute volume relationship but that will reduce the total weight of cementitious material since the specific gravities of pozzolanic materials are normally less than that of cement.

The equations for converting a target water-cement ratio w/c to a weight ratio of water to cement plus pozzolanic materials $w/(c+p)$ by (1) weight equivalency or (2) volume equivalency are as follows:

Eq. (6.3.4.1)—Weight equivalency

$$\frac{w}{c+p} \text{ weight ratio, weight equivalency} = \frac{w}{c}$$

where

$\frac{w}{c+p}$ = *weight of water divided by weight of cement + pozzolanic materials*

$\frac{w}{c}$ = *target water-cement ratio by weight*

When the weight equivalency approach is used, the percentage or fraction of pozzolanic materials used in the cementitious material is usually expressed by weight. That is, F_w the pozzolanic materials percentage by weight of total cement plus pozzolanic materials, expressed as a decimal factor, is

$$F_w = \frac{p}{c+p}$$

where

F_w = pozzolanic materials percentage by weight, expressed as a decimal factor
p = weight of pozzolanic materials
c = weight of cement

(Note: If only the desired pozzolanic materials percentage factor by absolute volume F_v is known, it can be converted to F_w as follows

$$F_w = \frac{1}{1 + \left(\frac{3.15}{G_p}\right)\left(\frac{1}{F_v} - 1\right)}$$

where

F_v = pozzolanic materials percentage by absolute volume of the total absolute volume of cement plus pozzolanic materials expressed as a decimal factor
G_p = specific gravity of pozzolanic materials
3.15 = specific gravity of portland cement [use actual value if known to be different])

Example 6.3.4.1 -- Weight equivalency

If a water-cement ratio of 0.60 is required and a fly ash pozzolan is to be used as 20 percent of the cementitious material in the mixture by weight ($F_w = 0.20$), then the required water-to-cement plus pozzolanic material ratio on a weight equivalency basis is

$$\frac{w}{c+p} = \frac{w}{c} = 0.60, \textit{ and}$$

$$F_w = \frac{p}{c+p} = 0.20$$

Assuming an estimated mixing-water requirement of 270 lb/yd^3, then the required weight of cement + pozzolan is 270 ÷ 0.60 = 450 lb; and the weight of pozzolan is (0.20)(450) = 90 lb. The weight of cement is, therefore, 450 - 90 = 360 lb. If instead of 20 percent fly ash by weight, 20 percent by absolute volume of cement plus pozzolan was specified (F_v = 0.20), the corresponding weight factor is computed as follows for a fly ash with an assumed gravity of 2.40:

$$F_w = \frac{1}{1 + \left(\frac{3.15}{G_p}\right)\left(\frac{1}{F_v} - 1\right)}$$

$$\frac{1}{1 + \left(\frac{3.15}{2.40}\right)\left(\frac{1}{0.2} - 1\right)}$$

$$F_w = \frac{1}{1 + (1.31)(4)} = \frac{1}{1 + 5.24} = \frac{1}{6.24} = 0.16$$

In this case 20 percent by absolute volume is 16 percent by weight, and the weight of pozzolan in the batch would be (0.16)(450) = 72 lb, and the weight of cement 450 - 72 = 378 lb.

Eq. (6.3.4.2) -- Absolute volume equivalency

$$\frac{w}{c+p} \text{ weight ratio, absolute volume equivalency} = \frac{3.15\frac{w}{c}}{3.15(1 - F_v) + G_p(F_v)}$$

where

$\frac{w}{c+p}$ = weight of water divided by weight of cement + pozzolanic materials

$\frac{w}{c}$ = target water-cement ratio by weight

3.15 = specific gravity of portland cement (use actual value if known to be different)

F_v = pozzolan percentage by absolute volume of the total absolute volume of cement plus pozzolan, expressed as a decimal factor

(Note: If only the desired pozzolan percentage by weight F_w is known, it can be converted to F_v as follows

$$F_v = \frac{1}{1 + \left(\frac{G_p}{3.15}\right)\left(\frac{1}{F_w} - 1\right)}$$

where these symbols are the same as defined previously.)

Example 6.3.4.2 -- Absolute volume equivalency

Use the same basic data as Example 6.3.4.1, but it should be specified that the equivalent water-to-cement plus pozzolan ratio be established on the basis of absolute volume, which will maintain, in the mixture, the same ratio of volume of water to volume of cementitious material when changing from cement only to cement plus pozzolan. Again the required water-cement ratio is 0.60, and it is assumed initially that it is desired to use 20 percent by absolute volume of fly ash (F_v = 0.20). The specific gravity of the fly ash is assumed to be 2.40 in this example

$$\frac{w}{c+p} = \frac{3.15\left(\frac{w}{c}\right)}{3.15(1 - F_v) + G_p(F_v)}$$

$$= \frac{(3.15)(0.60)}{(3.15)(0.80) + (2.40)(0.20)}$$

$$= \frac{1.89}{2.52 + 0.48} = \frac{1.89}{3.00} = 0.63$$

So the target weight ratio to maintain an absolute volume equivalency is $w/(c + p)$ = 0.63. If the mixing water is again 270 lb/yd³, then the required weight of cement + pozzolan is 270 ÷ 0.63 = 429 lb; and, since the corresponding weight percentage factor for F_v = 0.20 is F_w = 0.16 as calculated in Example 6.3.4.1, the weight of fly ash to be used is (0.16)(429) = 69 lb and the weight of cement is 429 - 69 = 360 lb. The volume equivalency procedure provides lower weights of cementitious materials. Checking the absolute volumes

$$\textit{fly ash} = \frac{69}{(2.40)(62.4)} = 0.461 ft^3$$

$$\textit{cement} = \frac{360}{(3.15)(62.4)} = 1.832 ft^3$$

$$\textit{total} = 0.461 + 1.832 = 2.293 ft^3$$

$$\textit{percent pozzolan by volume} = \frac{0.461}{2.293} \times 100 = 20 \textit{ percent}$$

If, instead of 20 percent fly ash by volume (F_v = 0.20), a weight percentage of 20 percent was specified (F_w = 0.20), it could be converted to F_v using G_p = 2.40 and the appropriate formula

$$F_v = \frac{1}{1 + \left(\frac{G_p}{3.15}\right)\left(\frac{1}{F_w} - 1\right)}$$

$$F_v = \frac{1}{1 + \left(\frac{2.40}{3.15}\right)\left(\frac{1}{0.2} - 1\right)}$$

$$F_v = \frac{1}{1 + (0.762)(4)} = \frac{1}{4.048} = 0.247$$

In this case 20 percent by weight is almost 25 percent by

APPENDI

211.1-12

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absolute volume. The equivalent $w/(c + p)$ ratio by volume will have to be recomputed for this condition since F_v has been changed from that originally assumed in this example

$$\frac{w}{c+p} = \frac{3.15\left(\frac{w}{c}\right)}{3.15(1-F_v) + G_p(F_v)}$$

$$= \frac{(3.15)(0.60)}{3.15(0.75) + 2.40(0.25)}$$

$$= \frac{1.89}{2.36 + 0.60} = \frac{1.89}{2.96} = 0.64$$

Total cementitious material would be 270 ÷ 0.64 = 422 lb. Of this weight 20 percent (F_w = 0.20) would be fly ash; (422)(0.20) = 84 lb of fly ash and 422 - 84 = 338 lb of cement.

6.3.5 *Step 5. Calculation of cement content* -- The amount of cement per unit volume of concrete is fixed by the determinations made in Steps 3 and 4 above. The required cement is equal to the estimated mixing-water content (Step 3) divided by the water-cement ratio (Step 4). If, however, the specification includes a separate minimum limit on cement in addition to requirements for strength and durability, the mixture must be based on whichever criterion leads to the larger amount of cement.

The use of pozzolanic or chemical admixtures will affect properties of both the fresh and hardened concrete. See ACI 212.

6.3.6 *Step 6. Estimation of coarse aggregate content* -- Aggregates of essentially the same nominal maximum size and grading will produce concrete of satisfactory workability when a given volume of coarse aggregate, on an oven-dry-rodded basis, is used per unit volume of concrete. Appropriate values for this aggregate volume are given in Table 6.3.6. It can be seen that, for equal workability, the volume of coarse aggregate in a unit volume of concrete is dependent only on its nominal maximum size and the fineness modulus of the fine aggregate. Differences in the amount of mortar required for workability with different aggregates, due to differences in particle shape and grading, are compensated for automatically by differences in oven-dry-rodded void content.

The volume of aggregate in ft^3, on an oven-dry-rodded basis, for a yd^3 of concrete is equal to the value from Table 6.3.6 multiplied by 27. This volume is converted to dry weight of coarse aggregate required in a yd^3 of concrete by multiplying it by the oven-dry-rodded weight per ft^3 of the coarse aggregate.

6.3.6.1 For more workable concrete, which is sometimes required when placement is by pump or when concrete must be worked around congested reinforcing steel, it may be desirable to reduce the estimated coarse aggregate content determined using Table 6.3.6 by up to 10 percent. However, caution must be exercised to assure that the resulting slump, water-cement or water-cementitious materials ratio, and strength properties of the concrete are consistent with the recommendations in Sections 6.3.1 and 6.3.4 and meet applicable project specification requirements.

6.3.7 *Step 7. Estimation of fine aggregate content* -- At completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity is determined by difference. Either of two procedures may be employed: the weight method (Section 6.3.7.1) or the absolute volume method (Section 6.3.7.2).

6.3.7.1 If the weight of the concrete per unit volume is assumed or can be estimated from experience, the required weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of the other ingredients. Often the unit weight of concrete is known with reasonable accuracy from previous experience with the materials. In the absence of such information, Table 6.3.7.1 can be used to make a first estimate. Even if the estimate of concrete weight per yd^3 is rough, mixture proportions will be sufficiently accurate to permit easy adjustment on the basis of trial batches as will be shown in the examples.

Table 6.3.6 — Volume of coarse aggregate per unit of volume of concrete

Nominal maximum size of aggregate, in.	Volume of oven-dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli of fine aggregate†			
	2.40	2.60	2.80	3.00
3/8	0.50	0.48	0.46	0.44
1/2	0.59	0.57	0.55	0.53
3/4	0.66	0.64	0.62	0.60
1	0.71	0.69	0.67	0.65
1 1/2	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

*Volumes are based on aggregates in oven-dry-rodded condition as described in ASTM C 29.
These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete, such as required for concrete pavement construction, they may be increased about 10 percent. For more workable concrete see Section 6.3.6.1.
†See ASTM C 136 for calculation of fineness modulus.

Table 6.3.7.1 — First estimate of weight of fresh concrete

Nominal maximum size of aggregate, in.	First estimate of concrete weight, lb/yd³*	
	Non-air-entrained concrete	Air-entrained concrete
3/8	3840	3710
1/2	3890	3760
3/4	3960	3840
1	4010	3850
1 1/2	4070	3910
2	4120	3950
3	4200	4040
6	4260	4110

*Values calculated by Eq. (6-1) for concrete of medium richness (550 lb of cement per yd^3) and medium slump with aggregate specific gravity of 2.7. Water requirements based on values for 3 to 4 in. slump in Table 6.3.3. If desired, the estimated weight may be refined as follows if necessary information is available: for each 10 lb difference in mixing water from the Table 6.3.3 values for 3 to 4 in. slump, correct the weight per yd^3 15 lb in the opposite direction; for each 100 lb difference in cement content from 550 lb, correct the weight per yd^3 15 lb in the same direction; for each 0.1 by which aggregate specific gravity deviates from 2.7, correct the concrete weight 100 lb in the same direction. For air-entrained concrete the air content for severe exposure from Table 6.3.3 was used. The weight can be increased 1 percent for each percent reduction in air content from that amount.

If a theoretically exact calculation of fresh concrete weight per yd^3 is desired, the following formula can be used

$$U = 16.85\ G_a\ (100 - A) + c(1 - G_a/G_c) - w(G_a - 1) \qquad (6\text{-}1)$$

where

- U = weight in lb of fresh concrete per yd^3
- G_a = weighted average specific gravity of combined fine and coarse aggregate, bulk SSD*
- G_c = specific gravity of cement (generally 3.15)
- A = air content, percent
- w = mixing water requirement, lb/yd^3
- c = cement requirement, lb/yd^3

6.3.7.2 A more exact procedure for calculating the required amount of fine aggregate involves the use of volumes displaced by the ingredients. In this case, the total volume displaced by the known ingredients--water, air, cementitious materials, and coarse aggregate--is subtracted from the unit volume of concrete to obtain the required volume of fine aggregate. The volume occupied in concrete by any ingredient is equal to its weight divided by the density of that material (the latter being the product of the unit weight of water and the specific gravity of the material).

6.3.8 *Step 8. Adjustments for aggregate moisture* -- The aggregate quantities actually to be weighed out for the concrete must allow for moisture in the aggregates. Generally, the aggregates will be moist and their dry weights should be increased by the percentage of water they contain, both absorbed and surface. The mixing water added to the batch must be reduced by an amount equal to the free moisture contributed by the aggregate -- i.e., total moisture minus absorption.

6.3.8.1 In some cases, it may be necessary to batch an aggregate in a dry condition. If the absorption (normally measured by soaking one day) is higher than approximately one percent, and if the pore structure within the aggregate particles is such that a significant fraction of the absorption occurs during the time prior to initial set, there may be a noticeable increase in the rate of slump loss due to an effective decrease in mixing water. Also, the effective water-cement ratio would be decreased for any water absorbed by the aggregate prior to set; this, of course, assumes that cement particles are not carried into aggregate particle pores.

6.3.8.2 Laboratory trial batch procedures according to ASTM C 192 allow the batching of laboratory air-dried aggregates if their absorption is less than 1.0 percent with an allowance for the amount of water that will be absorbed from the unset concrete. It is suggested by ASTM C 192 that the amount absorbed may be assumed to be 80 percent of the difference between the actual amount of water in the pores of the aggregate in their air-dry state and the nominal 24-hr absorption determined by ASTM C 127 or C 128. However, for higher-absorption aggregates, ASTM C 192 requires preconditioning of aggregates to satisfy absorption with adjustments in aggregate weight based on total moisture content and adjustment to include surface moisture as a part of the required amount of mixing water.

6.3.9 *Step 9. Trial batch adjustments* -- The calculated mixture proportions should be checked by means of trial batches prepared and tested in accordance with ASTM C 192 or full-sized field batches. Only sufficient water should be used to produce the required slump regardless of the amount assumed in selecting the trial proportions. The concrete should be checked for unit weight and yield (ASTM C 138) and for air content (ASTM C 138, C 173, or C 231). It should also be carefully observed for proper workability, freedom from segregation, and finishing properties. Appropriate adjustments should be made in the proportions for subsequent batches in accordance with the following procedure.

6.3.9.1 Re-estimate the required mixing water per yd^3 of concrete by multiplying the net mixing water content of the trial batch by 27 and dividing the product by the yield of the trial batch in ft^3. If the slump of the trial batch was not correct, increase or decrease the re-estimated amount of water by 10 lb for each 1 in. required increase or decrease in slump.

6.3.9.2 If the desired air content (for air-entrained concrete) was not achieved, re-estimate the admixture content required for proper air content and reduce or increase the mixing-water content of Paragraph 6.3.9.1 by 5 lb for each 1 percent by which the air content is to be increased or decreased from that of the previous trial batch.

6.3.9.3 If estimated weight per yd^3 of fresh concrete is the basis for proportioning, re-estimate that weight by multiplying the unit weight in lb/ft^3 of the trial batch by 27 and reducing or increasing the result by the anticipated percentage increase or decrease in air content of the adjusted batch from the first trial batch.

6.3.9.4 Calculate new batch weights starting with Step 4 (Paragraph 6.3.4), modifying the volume of coarse aggregate from Table 6.3.6 if necessary to provide proper workability.

CHAPTER 7 -- SAMPLE COMPUTATIONS

7.1 Two example problems will be used to illustrate application of the proportioning procedures. The following conditions are assumed:

7.1.1 Type I non-air-entraining cement will be used and its specific gravity is assumed to be 3.15.†

* SSD indicates saturated-surface-dry basis used in considering aggregate displacement. The aggregate specific gravity used in calculations must be consistent with the moisture condition assumed in the basic aggregate batch weights -- i.e., bulk dry if aggregate weights are stated on a dry basis, and bulk SSD if weights are stated on a saturated-surface-dry basis.

† The specific gravity values are not used if proportions are selected to provide a weight of concrete assumed to occupy 1 yd^3.

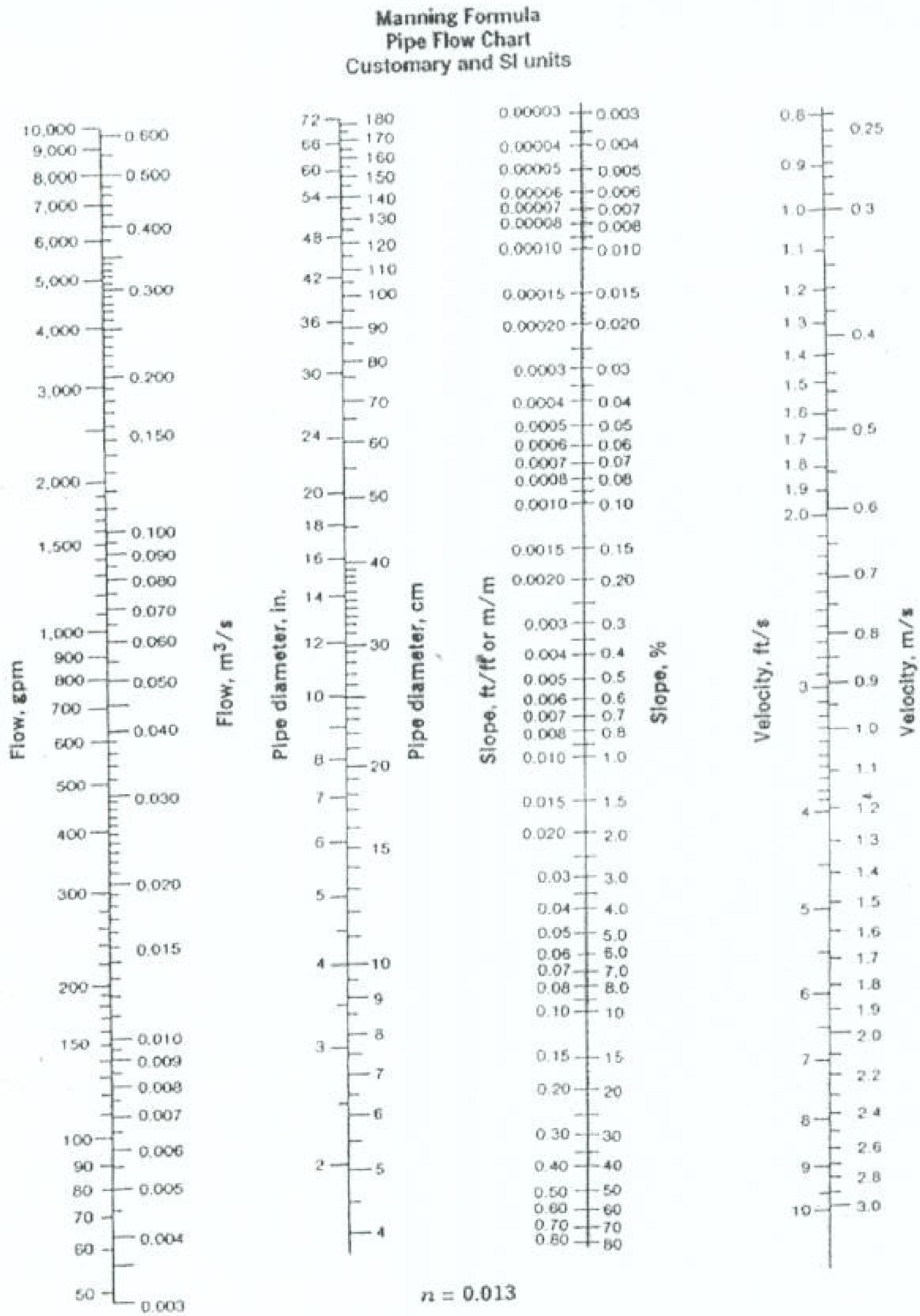


Chart based on the formula $Q = \frac{1.0 \text{ or } 1.5}{n} \times AR^{\frac{2}{3}} \times S^{\frac{1}{2}}$ for pipe flowing full.

FIGURE 2.21
Manning's nomograph *for circular pipes flowing full, with* n = *0.013. Manning's equation is used for open channel or gravity flow, whereas the Hazen–Williams equation is used for flow under pressure.* (Reprinted with permission from the U.S. Pipe and Foundry Company and Scranton Gillette Communications, Inc.)

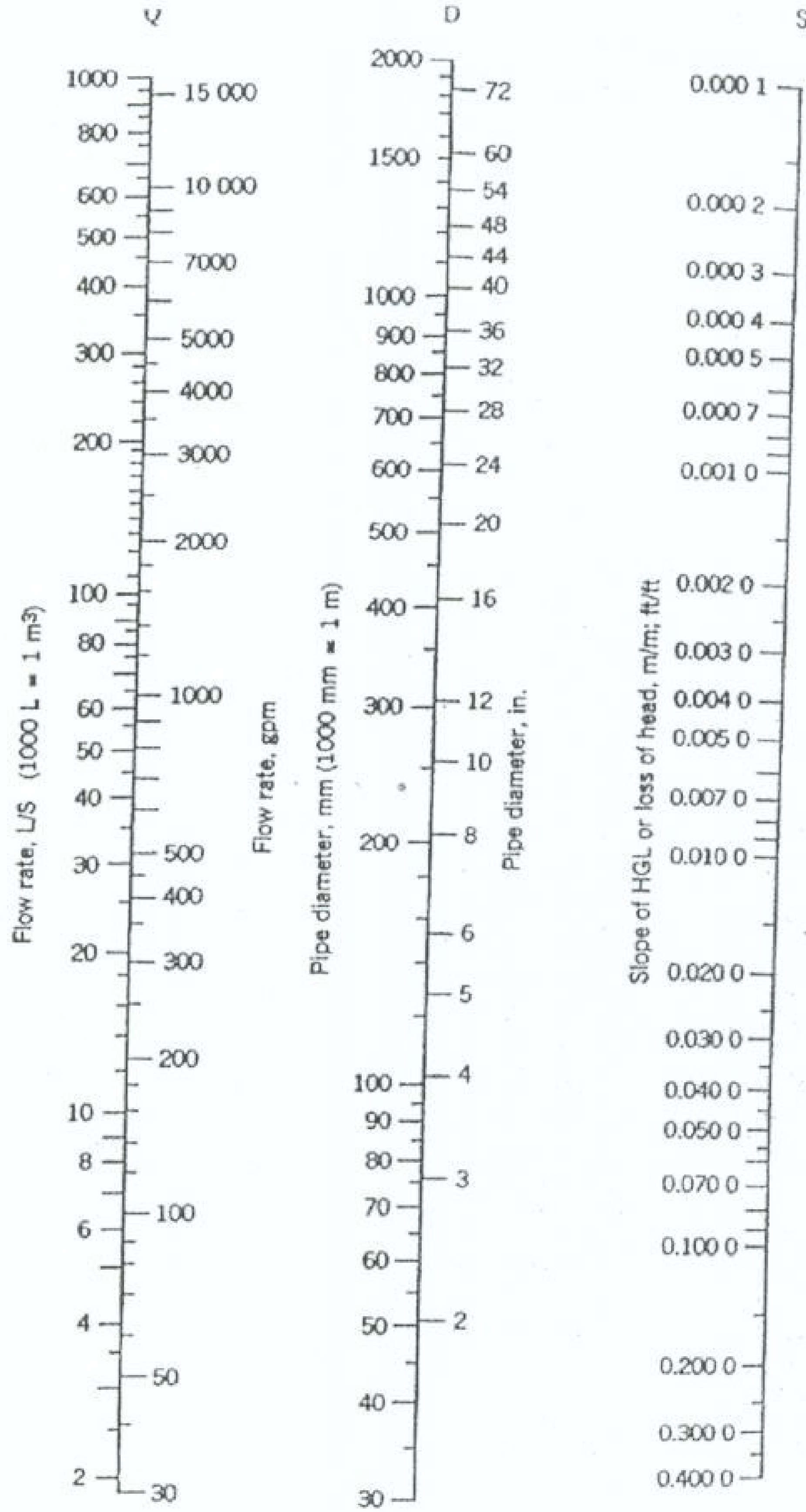


FIGURE 2.15

A nomograph that provides a graphical solution to the Hazen–Williams equation for water flowing in circular pipes under pressure, with C = 100.

Nomenclature:
d = partial depth
D = full depth or pipe diameter
q = partial discharge
Q = full-flow discharge
v = velocity, partially full
V = velocity, full

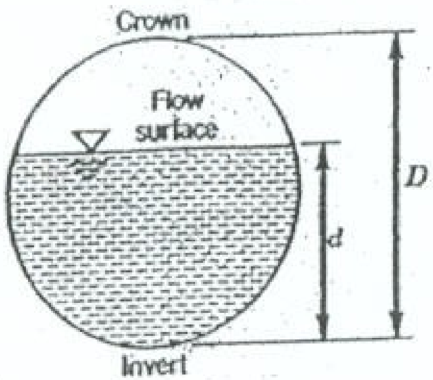
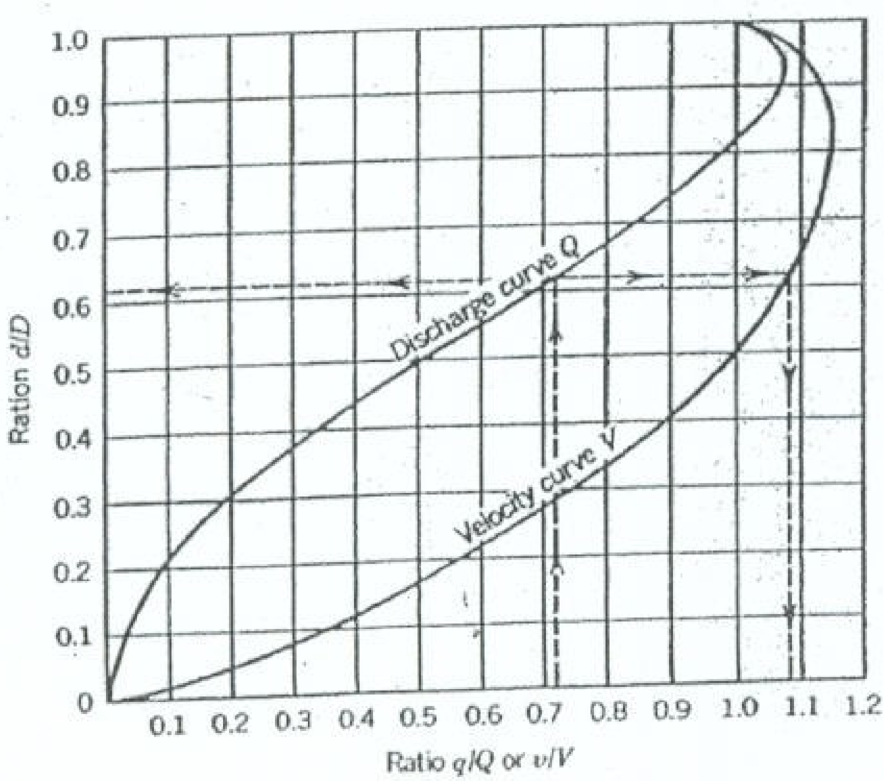


FIGURE 2.22
A partial-flow diagram *for a circular pipe that carries flow with the water surface below the pipe crown.*



Selected unit equivalences for conversions

Length

1 m = 1000 mm
1 m = 3.281 ft = 39.37 in.
1 in. = 25.4 mm
1 ft = 304.8 mm
1 mi = 5280 ft
1 km = 0.621 mi
1 yd = 3 ft

Area

$1\ m^2 = 10.764\ ft^2$
$1\ ac = 43{,}560\ ft^2$
$1\ ha = 10{,}000\ m^2 = 2.471\ ac$
$1\ km^2 = 0.386\ mi^2$

Volume

$1\ m^3 = 1000\ L = 264\ gal$
$1\ m^3 = 35.315\ ft^3 = 1.308\ yd^3$
$1\ ft^3 = 7.48\ gal$
1 L = 0.264 gal

Mass, Force, Weight

1 N = 0.225 lb
1 kg = 2.205 lb
1 (metric) ton = 1000 kg = 2205 lb
1 ton = 0.907 (metric) ton = 2000 lb

Mass and Weight Density

1 kg/L = 8.345 lb/gal
$1\ kN/m^3 = 172\ lb/yd^3$

Pressure

$1\ kPa = 1000\ N/m^2 = 0.147\ lb/in.^2$
1 atm = 100 kPa = 14.7 psi

Power

1 W = 1 N · m/s = 1 J/s
1 hp = 550 ft · lb/s = 746 W = 0.746 kW

Temperature

$$T_F = \frac{9}{5} T_c + 32 \text{ and } T_c = \frac{5}{9}(T_F - 32)$$

T_c = degrees Celsius
T_F = degrees Fahrenheit
T_K = Kelvins = T_c + 273 (20°C = 68°F = 293 K)

Metric prefixes and multipliers

Prefix	*Symbol*	*Multiplier*
giga	G	10^9
mega	M	10^6
kilo	k	10^3
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

U.S. customary units

Quantity	*Unit*	*Symbol*
Length	mile	mi
	yard	yd
	foot	ft
	inch	in.
Mass	slug	—
Area	square mile	mi^2
	acre	ac
	square foot	ft^2
	square inch	in^2
Force	pound	lb
	ton	—
Pressure	pounds per square inch	psi
Power	horsepower	hp
Temperature	degree Fahrenheit	°F
Volume	acre–foot	ac–ft
	cubic yard	yd^3
	cubic foot	ft^3
	cubic inch	in^3
	gallon	gal

Derived SI units

Quantity	*Unit*	*Symbol*	*Formula*
Area	hectare	ha	m^2
Energy	joule	J	N · m
Force	newton	N	$kg \cdot m/s^2$
Power	watt	W	J/s
Pressure	pascal	Pa	N/m^2
Volume	cubic meter	m^3	m^3